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Reanalysis of the "Märzorkan" of 1876

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Abstract

A heavy winter storm hit Western and Central Europe in March 1876 (the storm is termed "Märzorkan"). This paper analyses the meteorological situation during this event using the Twentieth Century Reanalysis version 2c (20CRv2c) data set. The "Märzorkan" was related to a low-pressure system that developed over the North Atlantic and moved towards Scandinavia. Strong westerly winds over Northern Europe were associated with this cyclone. The impacts of this extreme event originated both from high wind speeds and high precipitation amounts. A good agreement was found between 20CRv2c and historical reports, which therefore confirms the applicability of this data set for at least this extreme event.

1. Introduction

In Central Europe winter storms are amongst the most important and destructive meteorological hazards (Welker and Martius, 2015). In the last decades, heavy storm events such as "Lothar" (December 1999), "Kyrill" (January 2007; Welker and Martius, 2015) or more recently "Elon" and "Felix" (January 2015) have caused severe damage. Global warming might influence preconditions for the formation of extreme winter storms. For example, current models predict an increase in water vapour content in the atmosphere which has a cumulative effect on the intensity of a storm front (Wernli et al., 2002). There is however no consensus about past (*e.g.,* Matulla et al., 2008; Welker and Martius, 2014; Feser et al., 2015) or future (*e.g.,* Dawkins et al. 2016) changes in the frequency or intensity of winter storms in Europe.

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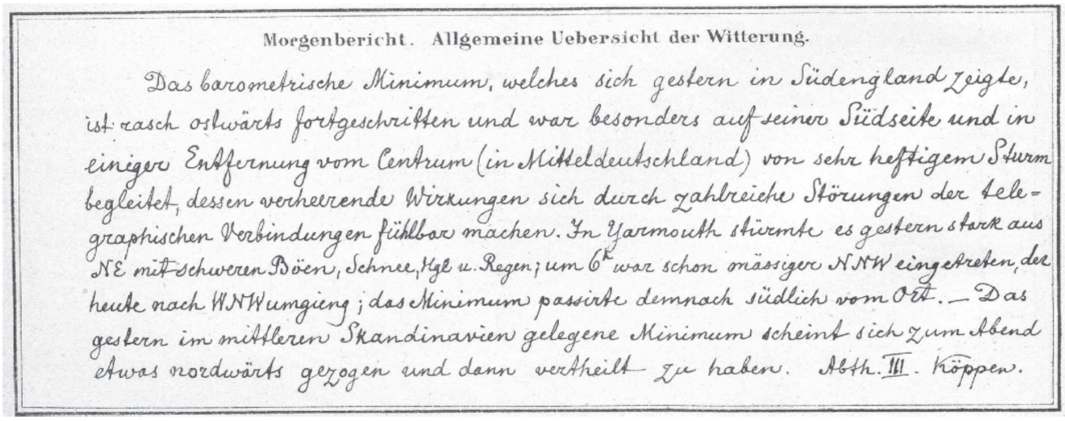

Morgenbericht. Allgemeine Uebersicht der Witterung.

Das barometrische Minimum, welches sich gestern in Südengland zeigte, ist rasch ostwärts fortgeschritten und war besonders auf seiner Südseite und in einiger Entfernung vom Centrum (in Mitteldeutschland) von sehr heftigem Sturm begleitet, dessen verheerende Wirkungen sich durch zahlreiche Störungen der telegraphischen Verbindungen fühlbar machen. In Yarmouth stürmte es gestern stark aus NE mit schweren Böen, Schnee, Hgl u. Regen; um 6^h war schon mässiger NNW eingetreten, der heute nach WNW umgieng; das Minimum passirte demnach südlich vom Ort. — Das gestern im mittleren Skandinavien gelegene Minimum scheint sich zum Abend etwas nordwärts gezogen und dann vertheilt zu haben. Abth. III. Köppen.

Figure 1. Part of the weather report 13 March 1876 from the Deutsche Seewarte (Reinert and Köppen, 1876a; source: Deutscher Wetterdienst).

Because of the rarity of extreme events with an intensity of “Lothar” or “Kyrill”, it is very important to gather as much information as possible from past storms. A good understanding of historical winter storms is essential to improve the knowledge of possible changes in winter storm occurrence in the future. In this paper, a historic storm event, the “Märzorkan” of 12 March 1876, is analysed as an example (see also Meyer et al., 2017 and Villiger et al., 2017, in this volume, for other winter storms over Western Europe).

Typical storm weather conditions in Western and Central Europe during the month of March 1876 fostered the development of an extreme storm from 9 to 11 March affecting parts of Western and Central Europe. In the morning of 12 March the intensive and destructive cyclone developed in the southwestern part of England. It then crossed northern France, the Benelux countries, Germany and Denmark. Figure 1 shows the storm as depicted in the weather report of the Deutsche Seewarte (Jelinek and Hann, 1876; Lowinski, 2007; Reinert and Köppen, 1876a, 1876b). According to Lowinski (2007) a wind gust with over 170 km/h was measured in Brussels on 12 March 1876.

The “Märzorkan” hit several densely populated areas and important industrial locations, causing severe damage. It destroyed numerous buildings, bridges and telegraph circuits. In particular the heavy rainfall caused widespread damages in the affected areas of the storm. Many cities were flooded, for example Koblenz shown in Figure 2, and high water levels were recorded in most of the rivers in the former German Reich (Jelinek and Hann, 1876; Lowinski, 2007).

The “Märzorkan” was investigated in several studies, both contemporary and present (*e.g.,* Jelinek and Hann, 1876; Lowinski, 2007; Scott, 1877). According to these reports, it is a typical storm event with a characteristic storm track and wind speeds at similar levels compared to other European winter storms in the last centuries (Jochner et al., 2013; Lamb and Frydendahl, 1991; Schneider et al., 2013; Welker and Martius, 2015; Wernli et al., 2002). At this point it should be noted that the “Märzorkan” is not mentioned in the book of Lamb and Frydendahl (1991) *Historic storms of the North Sea, British Isles, and Northwest Europe*.

The aim of this paper is to examine the “Märzorkan” in the Twentieth Century Reanalysis version 2c (20CRv2c) dataset (Compo et al., 2011). Particularly in the early decades, the quality of 20CRv2c needs to be assessed carefully. The present paper provides a case study of the representation of a heavy storm event in the 19^{th} century in 20CRv2c.

Figure 2. City of Koblenz, Germany, 12 March 1876 (from Stadtarchiv Koblenz, https://www.koblenz.de/stadtleben_kultur/stadtarchiv_eisenbahnsaeule_hochwassersaeule.html).

This paper is structured as follows. In Section 2, an overview about the data and methods used is given. The results are described in Section 3, which are then discussed and compared with other analysis in Section 4. Finally, conclusions are given in Section 5.

2. Data and Methods

The data used in the paper is the version 2c of the Twentieth Century Reanalysis (20CRv2c). 20CR is a global atmospheric dataset based only on the assimilation of surface and sea-level pressure (SLP) observations. An Ensemble Kalman Filter is used to assimilate the observations into the NCEP/GFS model (Saha et al., 2010), which uses sea-surface temperature (Giese et al., 2016) and sea-ice distribution as boundary conditions. The dataset has a six-hourly temporal resolution and a 2° x 2° latitude-longitude spatial resolution, 28 vertical levels and spans back to 1851 (Compo et al., 2011). The introductory paper to this book (Brönnimann, 2017) provides more details on this and other data sets used in this book.

The paper focuses on the variables 10-m wind speed, 850 hPa wind speed (note that this was calculated from the ensemble mean, not the individual members, and thus cannot be compared quantitatively with other data sets, although the time evolution should still provide meaningful results; see Brönnimann et al., 2013), SLP, and 500 hPa geopotential height (GPH). Additionally, daily precipitation is considered since floods were responsible for much of the damage. The domain of study and the stations used for the 20CRv2c assimilation for the assimilation interval at the peak of the storm are shown in Figure 3. The station network was still rather sparse in 1876 (see Meyer et al., 2017, for the same plot for 1881). For most of the analyses in this paper the ensemble mean is used, but we also analysed the ensemble spread (*i.e.,* standard deviation) and for some analyses the individual ensemble members.

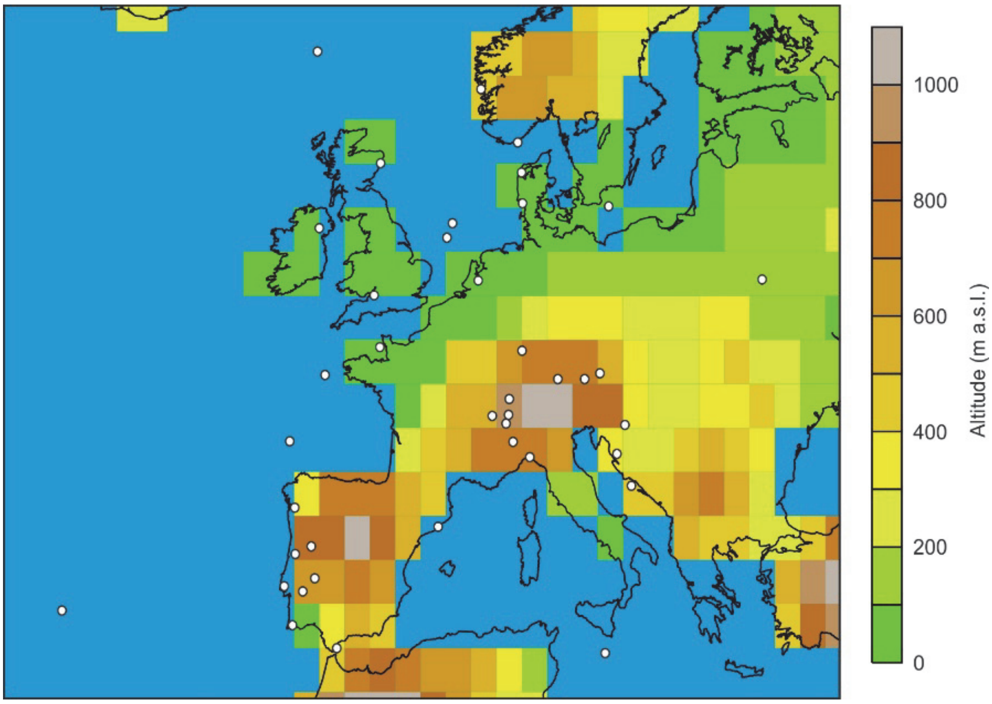

Figure 3. Domain of study, orography as represented in 20CR, and pressure observations assimilated into 20CRv2c on 12 March 1876, 6 UTC.

In order to track the storm, the pressure minima of the secondary pressure low of each time step from 12 March, 6 UTC, until 13 March, 12 UTC, was plotted. Further, the location of the minimum pressure was interpolated using the following equation (Eq. 1) for longitude and latitude separately, as proposed by Neff et al. (2013).

$$\varphi_{min} = \varphi_0 - \Delta\varphi \cdot \frac{p_1 - p_{-1}}{2 \cdot \left| p_0 - max(p_{-1}, p_1) \right|} \tag{1}$$

Here, p_{-1} and p_1 refer to the pressure at the grid points north and south (west and east), of the minimum in the gridded pressure field p_0, the latitude (or longitude) of p_0 is expressed by φ_0, and $\Delta\varphi$ is the spatial resolution of 20CR (*i.e.,* 2°).

For further analyses the 20CRv2c results were compared to historical weather maps. We used the information published in Scott (1877) as well as maps issued by the Deutsche Seewarte (Reinert and Köppen, 1876a, 1876b).

3. Results

Based on the analysis with 20CRv2c, in the evening of 8 March 1876 a low-pressure system was located north of Great Britain (not shown). During 9 March it strengthened and moved eastwards towards Scandinavia.

The depression reached its minimum pressure (~945 hPa) in the evening of 9 March. Accordingly, the geopotential height at 500 hPa was very low, around 4900 gpm. 48 hours later, the SLP at the centre had already increased to around 970 hPa (Fig. 4). On 12 March a secondary low-pressure system formed in southern England as shown in Fig. 4 (bottom left). During the next 24 hours this secondary low moved over the British Channel, the Benelux

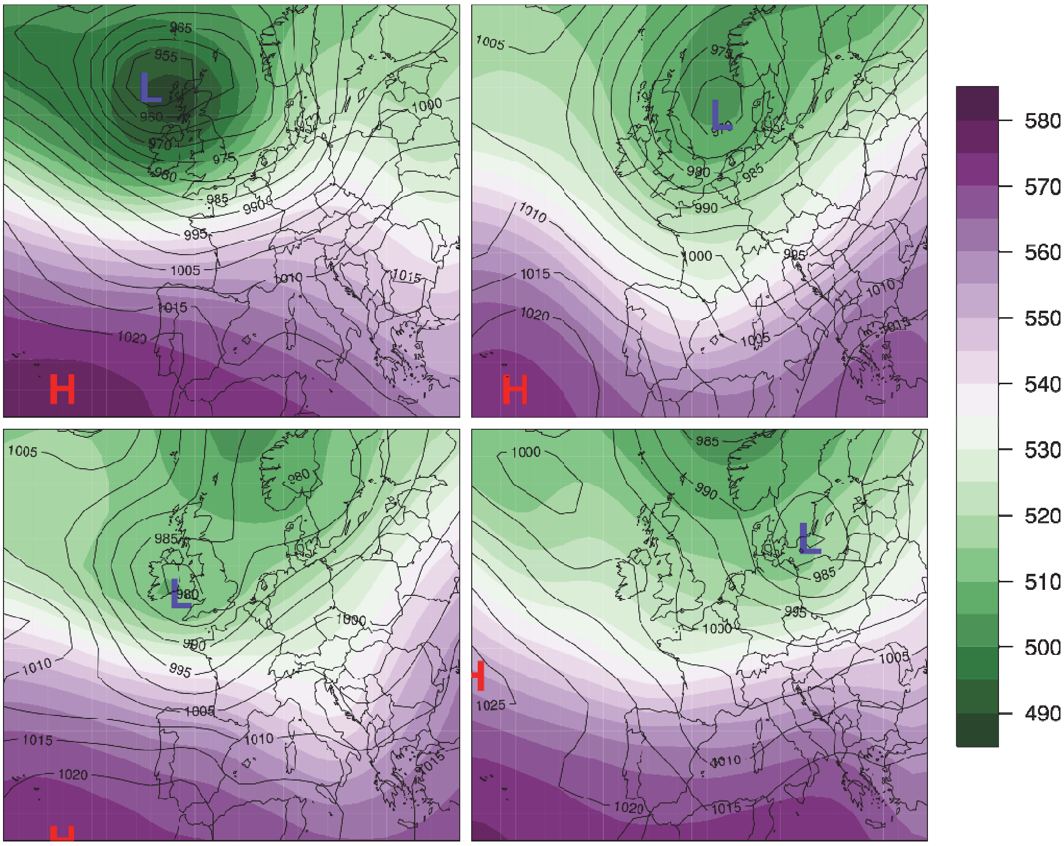

Figure 4. Sea-level pressure (contours) in hPa and geopotential height (colour shading) at 500 hPa during the “Märzorkan” of 1876. Panels show the situation on 9 March, 6 UTC (top left), 11 March, 6 UTC (top right), 12 March, 6 UTC (bottom left) and 13 March, 6 UTC (bottom right).

countries, Germany and towards the south-eastern part of the Baltic States (Fig. 4, bottom right). The track of the pressure low's minima during the main storm event on 12 March follows a clear path leading from Southern England over the British Channel to Northern France, the Benelux countries on to Germany and Denmark (Fig. 5). In Figure 4 (top left and top right) high pressure gradients over the Atlantic appear as well. In parallel, as the low-pressure system over Scandinavia weakened and a secondary low developed, the pressure gradient of the main low weakened and the gradient south of the secondary low over Benelux strengthened.

While Figure 4 shows the ensemble mean, we also analysed the ensemble spread. During the period of the storm, the ensemble spread of SLP remained below 2 hPa over almost the entire analysis domain except towards the central North Atlantic (not shown).

On 9 March the strong pressure low over the UK and the high pressure gradients caused heavy north-westerly winds off the coast of Ireland and south-westerly winds (>30 m s^{-1} at 850 hPa) from the eastern Atlantic to Germany (Fig. 6). The strength of the winds decreased on 11 March as the pressure low weakened. On 11 March wind speeds with values between 12.5 and 17.5 m s^{-1} appear in 20CRv2c (Fig. 6). On 12 March, the secondary low caused strong westerly winds over the Atlantic towards the French Coast with wind speeds around 25 to 30 m s^{-1} (Fig. 6). These winds weakened with the storm's progress onshore. Maximum wind speeds with approximately 26 m s^{-1} are found in 20CRv2c over northern France and northern Germany. On 13 March wind speeds above 20 m s^{-1} still occurred over Poland (Fig. 6).

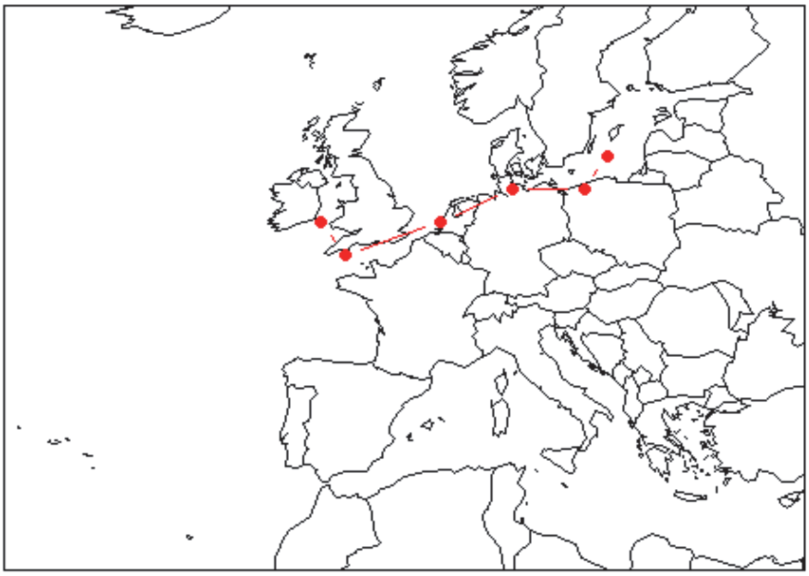

Figure 5. Track of the storm's pressure minima in the ensemble mean. The leftmost point indicates the storms position at 12 March 6 UTC and the rightmost point at 13 March 12 UTC, time steps between the points are 6 hours.

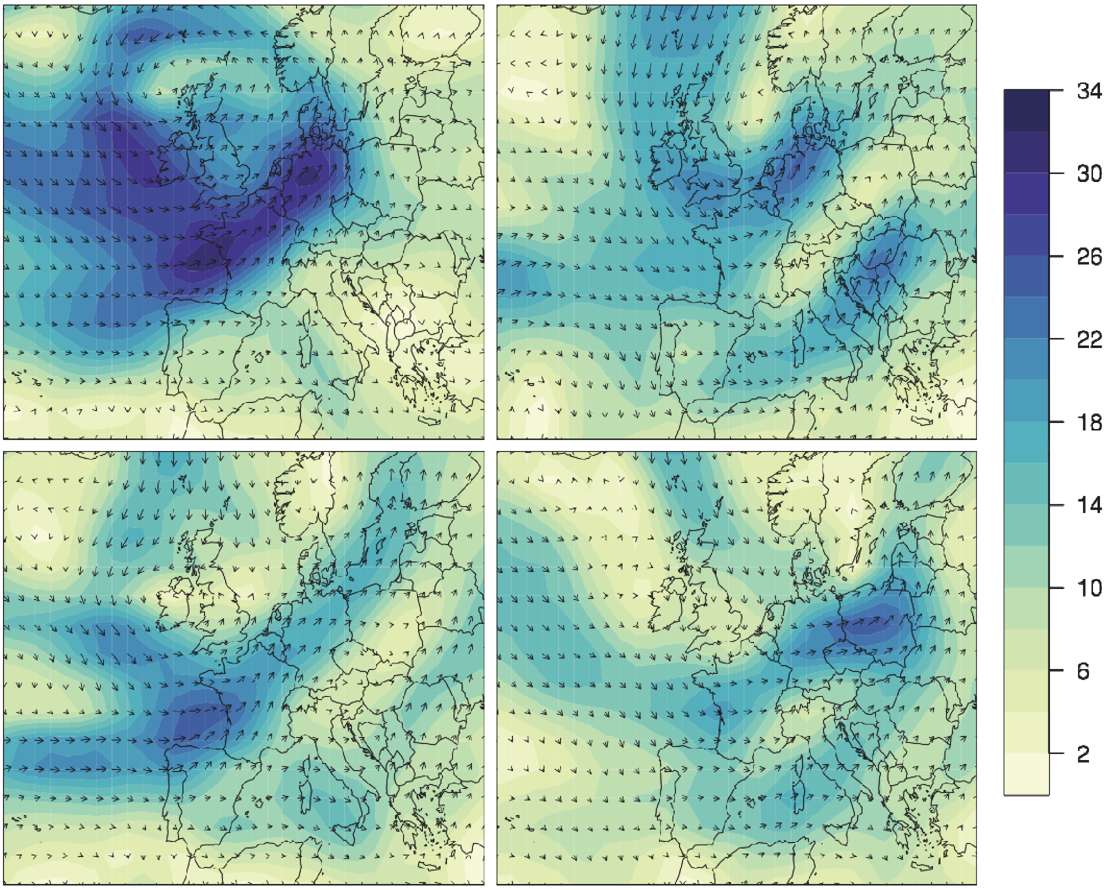

Figure 6. 850 hPa wind speed (colour shading) in m s^{-1} and wind direction during the "Märzorkan" of 1876. Panels show the situation on 9 March 6 UTC (top left), 11 March 6 UTC (top right), 12 March 6 UTC (bottom left) and 13 March 6 UTC (bottom right).

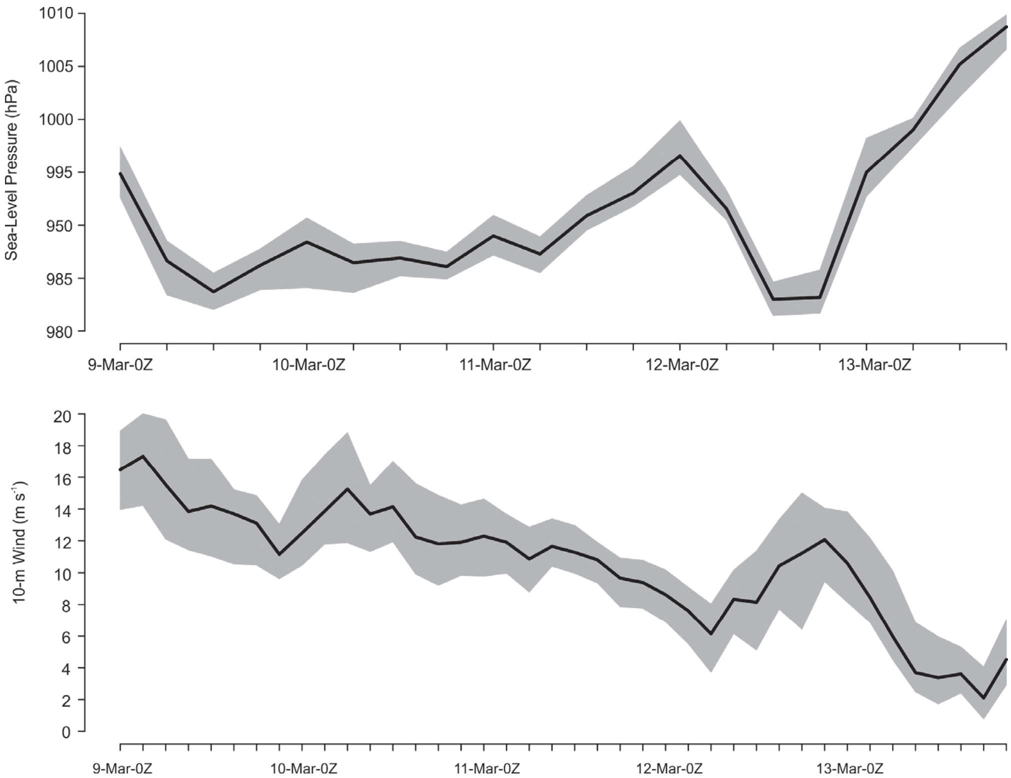

Figure 7. Time series of sea-level pressure in hPa (top) and 10-metre wind speed in m s^{-1} in 20CRv2c at the location of Brussels. The solid line and grey shading denote the ensemble mean and range.

SLP and 10-metre wind speed for the storm period were extracted from 20CRv2c for the location of Brussels (Fig. 7). Note that in this case, wind speed was calculated from the individual ensemble members. The evolution of these variables shows a first drop in pressure on 9 March (~985 hPa) and wind speeds around 17 m s^{-1}. A second drop in pressure linked to the secondary low is visible on 12 March (~983 hPa) with associated winds of ~12 m s^{-1}. The range of the 56 ensemble members amounts to around 5 hPa and 6 m s^{-1}, respectively. The ensemble range is much smaller than the variations for SLP, but less so for wind speed.

On 9 March the highest amounts of precipitation fell around the pressure low southwest of Scandinavia and over Germany as can be seen in Figure 8. Up to 26 mm d^{-1} fell around Köln. On 11 March, 20CRv2c displays almost no precipitation (Fig. 8, top right). However, again on 12 March, a considerable amount of precipitation of approximately 14 to 18 mm d^{-1} fell in France and Germany, roughly where the location of the storm can be assumed (Fig. 8, bottom left). The plot of 13 March does not show any strong precipitation event (Fig. 8, bottom right).

4. Discussion

Only sparse observations informed the 20CRv2c dataset, which in addition is based on a relatively coarse resolution model. Thus, the accuracy of the results obtained with 20CRv2c during the "Märzorkan" of 1876 is an interesting test case. Therefore, in this section the 20CRv2c reanalysis data is compared to scattered quotes in literature, the weather maps of the Deutsche Seewarte (Reinert and Köppen, 1876a, 1876b) (Fig. 9) and the maps created by Scott (1877) based on the measured data.

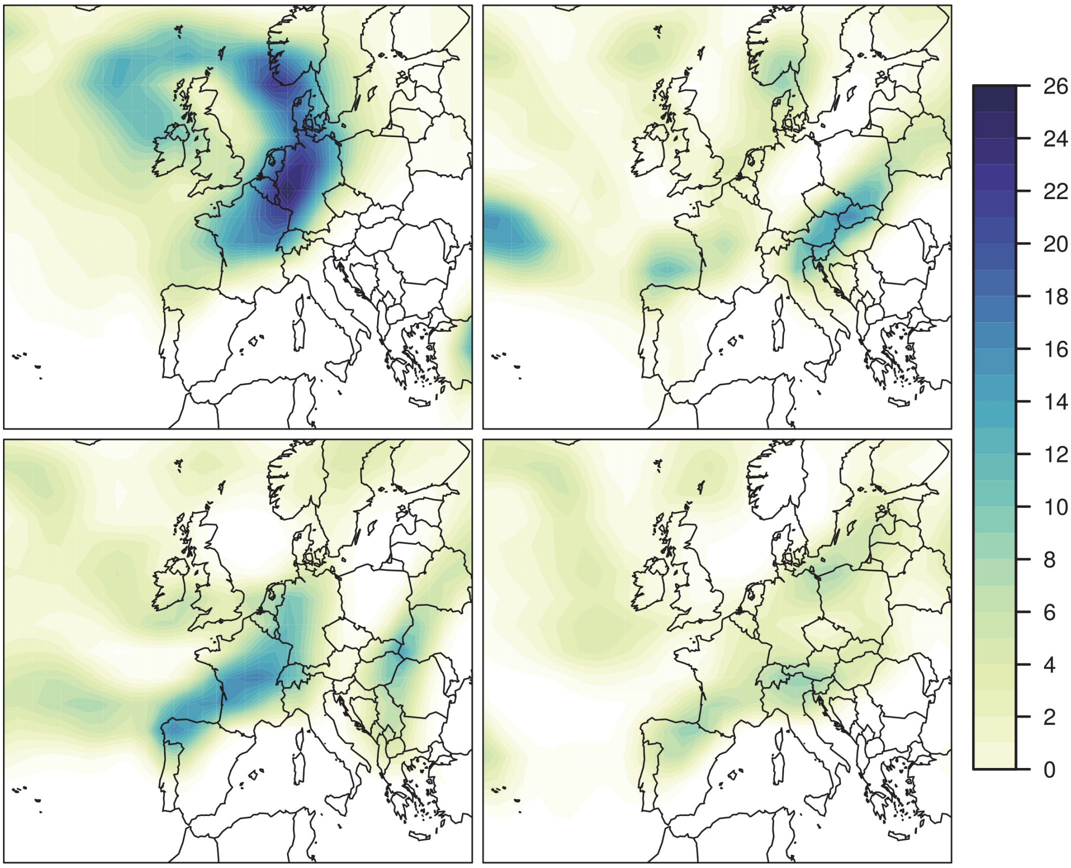

Figure 8. Daily precipitation accumulation in mm during the “Märzorkan” of 1876. Panels show the situation on 9 March 6 UTC (top left), 11 March 6 UTC (top right), 12 March 6 UTC (bottom left) and 13 March 6 UTC (bottom right).

According to the values in Scott (1877), the low-pressure system that initiated the “Märzorkan” lay north-east of Scotland in the morning of 9 March with a pressure value in the centre around 28.1 inches of mercury (inHg), which corresponds to approximately 950 hPa (Fig. 10, top left). As mentioned in Section 3, the ensemble mean of 20CRv2c shows a similar value with 945 hPa, which is thus in good agreement. Scott (1877) also describes the same track of the pressure minimum and equal pressure values during the following days (Fig. 10, top right). The historical pressure map (Fig. 10, bottom left) also proves the development of a secondary low on 12 March over South England. On the same day, Scott (1877) and Lowinski (2007) describe a fast movement of the pressure minimum from Southern England over the British Channel to Northern France, the Benelux countries to Germany and Denmark. This path is very similar to the one obtained with 20CRv2c data (Fig. 5). The lowest pressure value measured on 12 March at 8 UTC, according to Scott (1877), was 28.62 inHg (≈ 970 hPa). In 20CRv2c the minimum is around 980 hPa and is located slightly more to the north. Both historical and 20CRv2c pressure maps show that in the morning of 13 March the depression had continued towards the south-eastern part of the Baltic States and the pressure values were around 970 hPa in the ensemble mean of 20CRv2c (Fig. 9, bottom right) and 965 hPa on historical charts. As stated by Scott (1877), it is a remarkable fact that the values of the pressure minimum recorded over the various places along the storm track were almost identical.

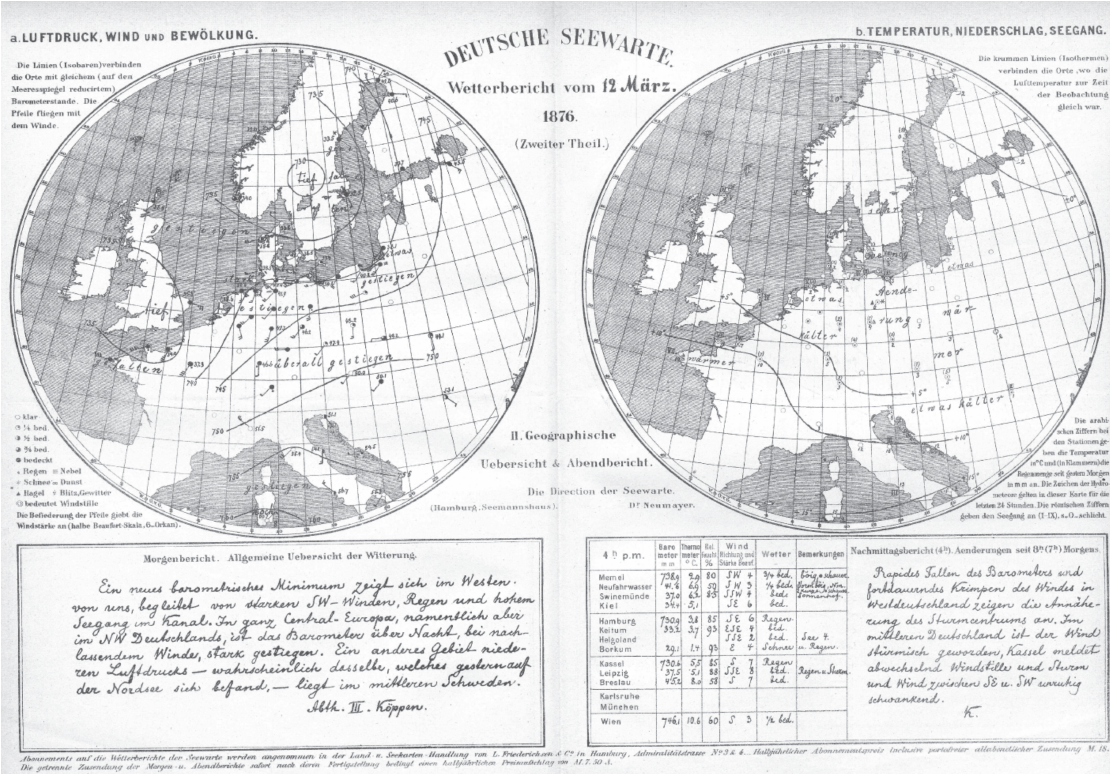

Figure 9. Weather report on 12 March 1876 from the Deutsche Seewarte (Reiner and Köppen, 1876b; source: Deutscher Wetterdienst).

The location of the pressure lows is well depicted in 20CRv2c but the pressure gradient is underestimated in the ensemble mean. This might explain why 10-m wind speeds in 20CRv2c are slightly lower than the observed values (note that wind speed in Fig. 7 is calculated from the ensemble members). Comparing 10-m wind speed between observations and 20CRv2c is difficult due on the one hand to issues of horizontal, vertical, and time resolution in 20CRv2c (*e.g.,* the lowest model level in 20CRv2c is at ca. 40 m and the 10-m wind is parametrized; given the coarse 2° resolution, surface roughness might not be locally representative; wind refers to the model state at a given time, not a maximum such as for wind gusts) and to observation uncertainties (station surroundings have a strong effect on wind speed, the exact height of the anemometer is mostly unknown, wind measurements are highly uncertain). This is discussed in the following.

According to Lowinski (2007) in northern and western France, northern and central Germany and Denmark mean wind speeds between 17.2 and 28.2 m s^{-1} have been reported during the “Märzorkan”. The averaging time used by Lowinski (2007) is not known. The maximum values of 10-m wind speed over land in Europe in 20CRv2c in the ensemble mean (calculated from the individual ensemble members) are around 15 m s^{-1}. A strong wind gust over 170 km h^{-1} (48 m s^{-1}) was measured on 12 March 1876 in Brussels (Lowinski, 2007), whereas 20CRv2c on that day shows a maximum ensemble mean wind speed of 15 m s^{-1} (highest member 19 m s^{-1}) in the area over Belgium (Fig. 7). This difference may be due to the fact that the observation represents a single gust, while 20CRv2c gives a state value representative for a three-hour interval.

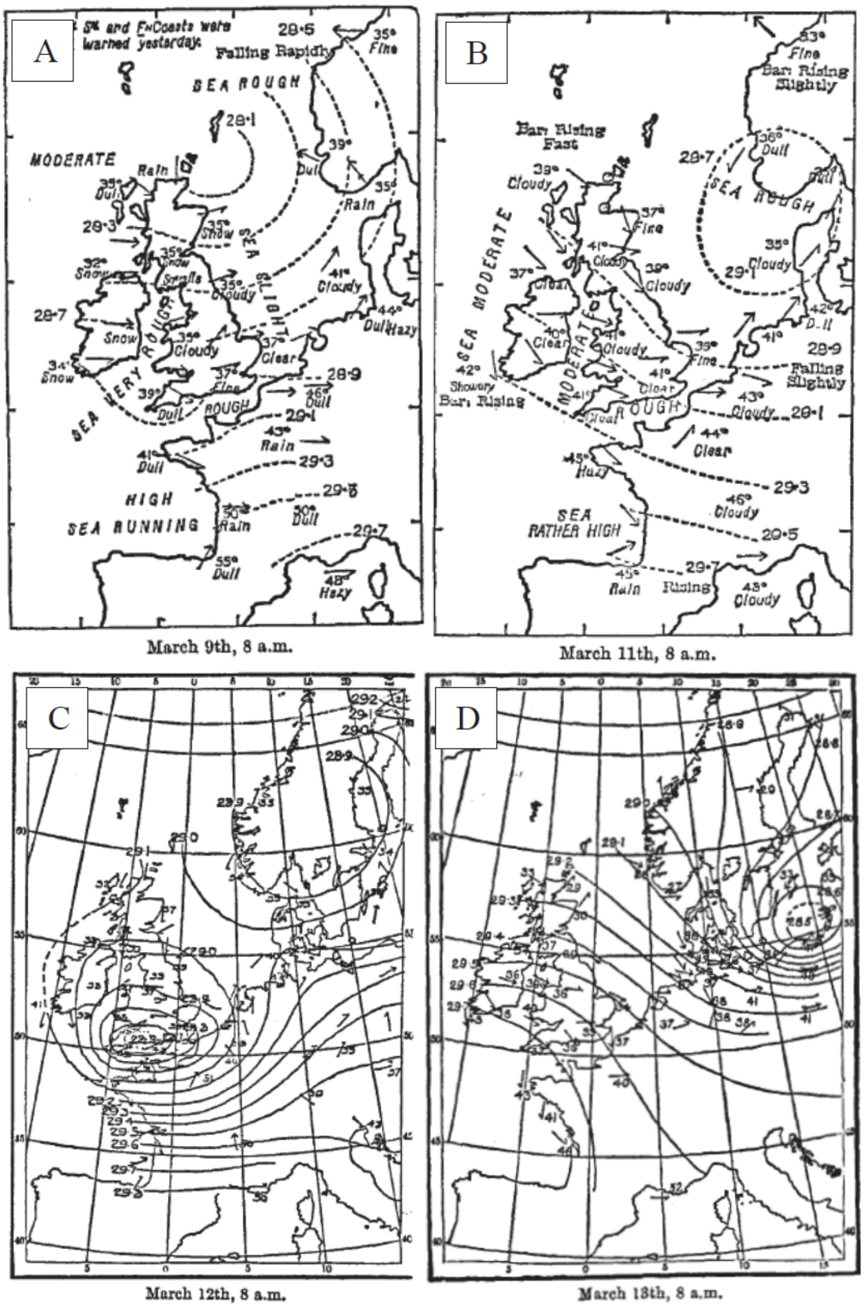

Figure 10. Sea-level pressure maps drawn by Scott (1877). Contours are in inHg.

During the “Märzorkan” not only wind speeds but also precipitation led to serious damages (Jelinek and Hann, 1876; Lowinski, 2007; Scott, 1877). According to Scott (1877), 0.9 inches of rain (22.86 mm) fell within 6 hours at Plymouth in the night from 11-12 March. This corresponds only little with the values obtained by the 20CRv2c data. The literature quotes indicate much more precipitation. They refer to persistent and heavy rainfall events which led to high water in numerous rivers, causing flooding (Jelinek and Hann, 1876; Lowinski, 2007; Scott 1877). The three-hourly precipitation rates in 20CRv2c (ensemble mean) amounted to ca. 14-18 mm d^{-1}, which is considerably less.

5. Conclusions

The comparison of the 20CRv2c data set with historical reports shows that they are in good quantitative agreement. The results obtained with 20CRv2c give a plausible overview of the meteorological situation that caused the “Märzorkan” of 1876. This concerns especially the development of the low-pressure system, including its track from the North Atlantic over Great Britain, France, the Benelux Countries and Germany towards Scandinavia. The values of the pressure minima are slightly overestimated in 20CR.

While it is remarkable that a good agreement of the evolution is found despite the coarse resolution of the reanalysis and the sparse observations that contributed, there are differences between observations and 20CRv2c arguably due to these factors. Phenomena that develop on a smaller scale, such as precipitation, seem to be difficult to capture realistically with 20CRv2c. The accuracy of the results about precipitation obtained in this paper is unsatisfactory. In particular with regard to the wind speeds depicted with 20CRv2c, the analysis shows that the number and locations of observations included in 20CRv2c might play a role. For further analysis it would be interesting to consider the individual ensemble members in more detail. Nevertheless, the reanalysis of the “Märzorkan” of 1876 confirms the applicability of 20CRv2c at least for analysing the storm development for this extreme case.

Acknowledgements

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References

Brönnimann, S. (2017) Weather Extremes in an Ensemble of Historical Reanalyses. In: Brönnimann, S. (Ed.) *Historical Weather Extremes in Reanalyses.* Geographica Bernensia G92, p. 7-22, DOI: 10.4480/GB2017.G92.01.

Brönnimann, S., O. Martius, J. Franke, A. Stickler, and R. Auchmann (2013) Historical weather extremes in the “Twentieth Century Reanalysis”. In: Brönnimann, S. and O. Martius (Eds.) *Weather extremes during the past 140 years*. Geographica Bernensia G89, p. 7-17, DOI: 10.4480/GB2013.G89.01.

Compo, G. P., J. S. Whitaker, P. D. Sardeshmukh, N. Matsui, R. J. Allan, X. Yin, B. E. Gleason, R. S. Vose, G. Rutledge, P. Bessemoulin, S. Brönnimann, M. Brunet, R. I. Crouthamel, A. N. Grant, P. Y. Groisman, P. D. Jones, M. Kruk, A. C. Kruger, G. J. Marshall, M. Maugeri, H. Y. Mok, Ø. Nordli, T. F. Ross, R. M. Trigo, X. Wang, S. D. Woodruff, and S. J. Worley (2011) The Twentieth Century Reanalysis Project. *Q. J. R. Meteorol. Soc.,* **137,** 1-28.

Dawkins, L. C., D. B. Stephenson, J. F. Lockwood, and P. E. Maisey (2016) The 21st century decline in damaging European windstorms. *Nat. Hazards Earth Syst. Sci.,* **16,** 1999-2007.

Feser, F., M. Barcikowska, O. Krueger, F. Schenk, R. Weisse, and L. Xia (2015) Storminess over the North Atlantic and northwestern Europe—A review. *Q. J. R. Meteorol. Soc,* **141,** 350–382.

Giese, B. S., H. F. Seidel, G. P. Compo, and P. D. Sardeshmukh (2016) An ensemble of ocean reanalyses for 1815-2013 with sparse observational input. *J. Geophys. Res. Ocean.,* **121,** 6891–6910.

Jelinek, C. and J. Hann (1876) Über die Stürme des Monats März 1876 in Europa. *Z. österr. Ges. Meteorol.,* **11,** 241-250.

Jochner, M., M. Schwander, and S. Brönnimann (2013) Reanalysis of the Hamburg Storm Surge of 1962. In: Brönnimann, S. and O. Martius (Eds.) *Weather extremes during the past 140 years.* Geographica Bernensia G89, p. 19-26, DOI: 104480/GB2013.G89.02.

Lamb, H. H. and K. Frydendahl (1991) *Historic storms of the North Sea, British Isles, and Northwest Europe.* Cambridge: Cambridge University Print.

Lowinski, L. (2007) Der grosse März-Orkan vom 12.03.1876. München, METEOS GmbH.

Matulla, C., W. Schoener, H. Alexandersson, H. von Storch, and X. L. Wang (2008) European storminess: late nineteenth century to present. *Clim. Dynam.* **31,** 125–130.

Meyer, L., R. Hunziker, J. Weber, and A. Zürcher (2017) An Analysis of the “Great Gale of October 1881“ using the Twentieth Century Reanalysis. In: Brönnimann, S. (Ed.) *Historical Weather Extremes in Reanalyses.* Geographica Bernensia G92, p. 91-100, DOI: 10.4480/GB2017.G92.10.

Neff, B., C. Kummli, A. Stickler, J. Franke, and S. Brönnimann (2013) An analysis of the Galveston Hurricane using the 20CR data set. In: Brönnimann, S. and O. Martius (Eds.) *Weather extremes during the past 140 years.* Geographica Bernensia G89, p. 27-34, DOI: 104480/GB2013.G89.03.

Reinert, J. V. and W. P. Köppen (1876a). Wetterbericht von Montag dem 13ten März. Deutsche Seewarte.

Reinert, J. V. and W. P. Köppen (1876b). Wetterbericht von Sonntag dem 12ten März. Deutsche Seewarte.

Saha, S., S. Moorthi, H.-L. Pan, X. Wu, J. Wang, S. Nadiga, P. Tripp, R. Kistler, J. Woollen, D. Behringer, H. Liu, D. Stokes, R. Grumbine, G. Gayno, J. Wang, Y.-T. Hou, H.-Y. Chuang, H.-M. H. Juang, J. Sela, M. Iredell, R. Treadon, D. Kleist, P. Van Delst, D. Keyser, J. Derber, M. Ek, J. Meng, H. Wei, R. Yang, S. Lord, H. Van Den Dool, A. Kumar, W. Wang, C. Long, M. Chelliah, Y. Xue, B. Huang, J.-K. Schemm, W. Ebisuzaki, R. Lin, P. Xie, M. Chen, S. Zhou, W. Higgins, C.-Z. Zou, Qu. Liu, Y. Chen, Y. Han, L. Cucurull, R. W. Reynolds, G. Rutledge, and M. Goldberg (2010) The NCEP Climate Forecast System Reanalysis. *Bull. Amer. Meteorol. Soc.,* **91,** 1015-1057.

Schneider, T., H. Weber, J. Franke, and S. Brönnimann (2013) The Storm Surge Event of the Netherlands in 1953. In: Brönnimann, S. and O. Martius (Eds.) *Weather extremes during the past 140 years.* Geographica Bernensia G89, p. 35-43, DOI: 104480/GB2013.G89.04.

Scott, R. H. (1877) On the Storm which passed over the South of England, March 12th, 1876. *Q. J. R. Meteorol. Soc.,* **3,** 159–175.

Villiger, L., M. Schwander, L. Schürch, L. Stanisic, and S. Brönnimann (2017) The “Royal Charter” Storm of 1859. In: Brönnimann, S. (Ed.) *Historical Weather Extremes in Reanalyses.* Geographica Bernensia G92, p. 35-45, DOI: 10.4480/GB2017.G92.03.

Welker, C. and O. Martius (2014) Decadal-scale variability in hazardous winds in northern Switzerland since end of the 19th century. *Atmos. Sci. Lett.,* **15,** 86–91.

Wernli, H., S. Dirren, M. A. Liniger, and M. Zillig (2002) Dynamical aspects of the life cycle of the winter storm ‘Lothar’ (24–26 December 1999). *Q. J. R. Meteorol. Soc.,* **128,** 405–429.